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THE USE OF LANDSAT DATA TO STUDY MESOSCALE CLOUD FEATURES

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16. Abstract

The objective of this study is the use of Landsat data to investigate cumulus cloud banding and the processes which cause it, as well as to correlate meteorological conditions with other mesoscale cloud situations observed by Landsat. Analysis of a complex cloud banding case over the Adirondacks on 20 July 1974 gave evidence that processes other than those recognized by the Rayleigh-Kuettner theory are capable of giving rise to cloud bands. Other situations studied verified that elementary wave theory is useful under proper conditions.

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PREFACE

The purpose of this investigation is the use of Landsat data to study cumulus cloud banding and other mesoscale cloud features. The specific objectives are two: to study cumulus cloud banding and determine the physical processes which cause it, and to study the relationships between meteorological conditions and other mesoscale cloud features observed by Landsat satellites. These cloud features may include heat island effects caused by urban areas, severe weather situations, tropical cloudiness, high latitude clouds caused by heating from below, transverse waves in cirrus and middle-level clouds, and vortices in stratus cloud fields.

During the fourth quarter of this study 98 Landsat-1 photographs were obtained from NOAA-NESS, showing several cases of cloud banding and wave clouds and a few other mesoscale features. Those which were made over areas with adequate ground truth have been selected for analysis which is now being completed.

Analysis of cumulus cloud banding cases continued with emphasis placed upon the relationships among the three dimensions of cloud bands and their organization in layers with different flow characteristics and vertical distribution of temperature and moisture. A difficulty encountered with Landsat photographs taken during high elevations of the sun is the reduced accuracy with which the height of cloud tops can be determined from their shadows. The error increases with increasing diameter to depth ratio of the cloud elements. A rather thorough literature review of past observational work produced rather compelling evidence for the cloud depth to band spacing ratio $\frac{H}{\lambda y}$ to lie somewhere between 1/2 and 1/3.

For those cases in which the cloud shadow measurements produced large departures from this ratio H was set at 0.4 λy and the maximum and average windspeeds in the layer were computed accordingly. A method was developed for estimating vertically averaged and maximum windspeed in layers with cloud banding viewed over data-silent areas, using the depth of the clouds, their spacing within a band and the spacing of the cloud bands and the climatologically estimated average temperature of the layer.

Comparison of the results for cases with ground truth suggests that average windspeeds with those computed from neighboring soundings compare within a factor of 2.

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1. INTRODUCTION

1.1 Purpose and Objectives

The purpose of this investigation is the use of Landsat data to study cumulus cloud banding and other mesoscale cloud features. Specifically, this project has two objectives: to study cumulus cloud banding and the physical processes which cause it, and to correlate meteorological conditions with other mesoscale cloud situations observed by Landsat. In particular, this study will derive cloud banding parameters from satellite photographs and relate these parameters to the appropriate meteorological and topographic conditions. The results of this analysis will then be compared to the results predicted by theories of shear instability in the Ekman boundary layer.

Because of the areal coverage and detailed spatial resolution provided by the Landsat 1 and 2, the satellite photographs are ideal in studying mesoscale cloud conditions. The results of this study should, therefore, permit a better understanding of the formation and characteristics of various mesoscale cloud features. Furthermore, since cumulus cloud banding is closely related to the low level wind field, the results of the study may also lead to the development of new techniques for deriving winds in data sparse areas.

1.2 Summary of Work Performed During the Reporting Period

During this reporting period the work emphasized the verification of the flow characteristics of the airmass in which cloud bands and wave clouds were observed. The cases received during this quarter included 18 examples of cumulus cloud banding and four of wave clouds.

The analysis of mesoscale features continued with a detailed study of 18 July 1975 cumulus banding case over Texas and Louisiana and studies of the wave clouds seen on 6 April 1973 over Connecticut and Rhode Island. It was found that the transition from wave clouds to irregularly scattered and clustered cumulus clouds takes place abruptly over a distance as short as 15 kilometers, without change of wavelength.

2. PROGRESS DURING THE REPORTING PERIOD

2.1 Data Collection

During this period, 98 cases of mesoscale cloud features were received from NOAA-NESS. These photos were selected at the U.S.G.S. in Boston using their browse file. These pictures were received in early December and some have been selected as study cases; others have been put aside due to data sparseness needed for cloud street verification techniques. Photographs are 9.5" x 9.5" Black and White paper prints.

SUMMARY OF LANDSAT PHOTOGRAPHS SELECTED

Observation Identifier	Sensor Band	Product Type	Product Format	Number Of Copies
11 Aug 75	5	E 2201	16471	1
13 Aug 75	5	E 2203	16531	1
13 Aug 75	5	E 2203	16575	1
13 Aug 75	5	E 2203	16581	1
13 Aug 75	5	E 2203	18363	1
13 Aug 75	5	E 2203	15122	1
14 Aug 75	5	E 2204	15190	1
14 Aug 75	5	E 2204	15213	1
14 Aug 75	5	E 2204	17024	1
14 Aug 75	5	E 2204	17033	1
15 Aug 75	5	E 2205	15264	1
23 Jun 75	5	E 2152	17114	1
23 Jun 75	5	E 2152	17121	1
23 Jun 75	5	E 2152	17123	1
23 Jun 75	5	E 2152	17130	1
23 Jun 75	5	E 2152	17132	1
23 Jun 75	5	E 2152	17135	1
23 Jun 75	5	E 2152	17141	1
23 Jun 75	5	E 2152	17144	1
23 Jun 75	5	E 2152	17150	1
23 Jun 75	5	E 2152	17153	1
23 Jun 75	5	E 2152	17155	1
24 Jun 75	5	E 2153	15300	1
24 Jun 75	5	E 2153	15382	1
24 Jun 75	5	E 2153	15385	1
24 Jun 75	5	E 2153	14500	1
25 Jun 75	5	E 2154	13593	1
25 Jun 75	5	E 2154	15400	1
4 Jul 75	5	E 2163	14482	1
4 Jul 75	5	E 2163	14491	1
4 Jul 75	5	E 2163	14493	1
4 Jul 75	5	E 2163	14500	1
4 Jul 75	5	E 2163	14514	1
24 Jul 75	5	E 2153	17164	1
24 Jun 75	5	E 2153	17170	1

SUMMARY OF LANDSAT PHOTOGRAPHS SELECTED (cont)

Observation Identifier	Sensor Band	Product Type	Product Format	Number Of Copies
24 Jun 75	5	E 2153	17173	1
24 Jun 75	5	E 2153	17175	1
24 Jun 75	5	E 2153	17182	1
24 Jun 75	5	E 2153	17104	1
24 Jun 75	5	E 2153	17191	1
24 Jun 75	5	E 2153	17193	1
24 Jun 75	5	E 2153	17200	1
24 Jun 75	5	E 2153	17211	1
24 Jun 75	5	E 2153	17220	1
24 Jun 75	5	E 2153	17202	1
27 Jun 75	5	E 2156	17344	1
27 Jun 75	5	E 2156	17350	1
27 Jun 75	5	E 2156	17355	1
27 Jun 75	5	E 2156	17362	1
27 Jun 75	5	E 2156	17371	1
27 Jun 75	5	E 2156	17385	1
28 Jun 75	5	E 2157	17405	1
28 Jun 75	5	E 2157	17411	1
28 Jun 75	5	E 2157	17414	1
28 Jun 75	5	E 2157	17420	1
28 Jun 75	5	E 2157	17423	1
2 Jul 75	5	E 2161	16223	1
1 Jul 75	5	E 2160	17565	1
1 Jul 75	5	E 2160	17571	1
1 Jul 75	5	E 2160	17585	1
1 Jul 75	5	E 2160	18001	1
30 Jun 75	5	E 2159	16084	1
30 Jun 75	5	E 2159	16090	1
2 Jul 75	5	E 2161	18043	1
3 Jul 75	5	E 2162	16282	1
3 Jul 75	5	E 2162	16284	1
3 Jul 75	5	E 2162	16291	1
3 Jul 75	5	E 2162	16300	1
3 Jul 75	5	E 2162	16305	1
3 Jul 75	5	E 2162	14423	1
3 Jul 75	5	E 2162	14441	1
3 Jul 75	5	E 2162	18102	1
3 Jul 75	5	E 2162	18111	1
3 Jul 75	5	E 2162	18483	1
4 Jul 75	5	E 2163	18142	1
4 Jul 75	5	E 2163	18145	1
4 Jul 75	5	E 2163	16345	1
4 Jul 75	5	E 2163	16354	1
4 Jul 75	5	E 2163	16361	1
4 Jul 75	5	E 2163	16363	1
6 Jul 75	5	E 2165	15003	1
6 Jul 75	5	E 2165	14594	1
6 Jul 75	5	E 2165	15033	1
6 Jul 75	5	E 2165	15044	1
6 Jul 75	5	E 2165	21452	1

SUMMARY OF LANDSAT PHOTOGRAPHS SELECTED (cont)

Observation Identifier	Sensor Band	Product Type	Product Format	Number Of Copies
6 Jul 75	5	E 2165	21454	1
8 Jul 75	5	E 2167	15125	1
10 Jul 75	5	E 2169	20254	1
12 Jul 75	5	E 2171	15363	1
15 Jul 75	5	E 2174	17370	1
16 Jul 75	5	E 2175	17424	1
18 Jul 75	5	E 2177	16123	1
18 Jul 75	5	E 2177	16130	1
18 Jul 75	5	E 2177	17525	1
18 Jul 75	5	E 2177	21110	1
19 Jul 75	5	E 2178	16104	1
19 Jul 75	5	E 2178	16190	1
19 Jul 75	5	E 2178	16195	1
25 Jul 75	5	E 2184	15101	1
25 Jul 75	5	E 2184	15110	1

2.2 Data Analysis

Many Landsat-2 images have been ordered and received since the last reporting period. At least five have been analyzed completely or are in the process of being completed and new investigations are already started on seven more.

The Texas-Louisiana 18 July 75 case has been completed. Wind profiles and radiosonde soundings were plotted. Terrain conditions were favorable for maximum windspeed calculations which were quite realistic. Isobaric analysis was not possible due to a lack of surface data needed to obtain accurate mesoscale analysis. Comparisons of cloud street patterns in relation to pressure fields could not be studied in this case. This proved to be a problem with most all cases studied during this last quarter. Ground truth is simply not adequate enough to obtain the necessary information to make accurate comparisons.

Landsat-2 imagery of 8 July 75 revealed similar results as those in the earlier study of 20 July 74. Due to mountainous terrain low level flow was not smooth. Mechanically induced waves were quite evident. Isobaric analysis was performed but in mountainous areas cloud streets did not follow the pressure field. In lower terrain of Pennsylvania, cloud streets which did form were more closely aligned with the pressure field than the wind field, a feature noted earlier in previous case studies.

Analysis of wave clouds are also in progress during this reporting period. Seven cases, many over the New England, New York area are being analyzed. Most of the analysis indicates that cloud formations bear out wave theory expectations.

It was found that during the summer and over low latitudes the elevation of the sun was often close to 60 degrees. The geometry of the incident radiation upon simple pyramidal trapezoidal and rectangular cloud models shows that measurements of the length of the cloud shadows, whether taken from the center of from the edge of the cloud are subject to error, unless the cumulus tower closely resembles a cone of which the angle between the diameter of the base and the slant height is equal to or larger than the sun's elevation. The error increases with departure from a pyramidal or conical shape and with increasing diameter to depth ratio. Where the theoretically derived and observationally confirmed ratio of cloud street spacing to layer depth ratio $2.0 < \frac{\lambda y}{H} < 3.0$ was not found, the computed cloud top heights were assumed to be in error and omitted from the analysis. Instead, H was set at 0.4 λy.

However, the most important progress during the last three months is the development and testing of a simple model for better assessment of the balance of forces that maintain the spiraling circulation in cloud bands. It is based on the assumption that buoyant forces, β, are present over at least a tenth of the cloudy area and restoring forces (which oppose the circulation) over the remainder of the region encompassed by two neighboring cloud streets. Based on the conservation principles of mass and energy a simple relationship can be derived among the spacing of cloud bands λy, the spacing of cloud elements in a band λx, the average temperature $\overline{T}$ in the airmass, the corresponding difference between Γ_m, the moist adiabatic and Γ_d, the dry adiabatic temperature lapse rate and the buoyancy β (the driving force to maintain the circulation) namely:

$$\beta = \frac{KE}{\overline{T}} \left[\frac{\lambda x}{\lambda y} (\Gamma_m - \Gamma_d)\right] \qquad KE \approx 0.1$$

β, λx, λy and the depth H of the cloud layer are used, as before, to compare the maximum wind by means of the Rayleigh-Kuettner theory. Investigation of the Rayleigh-Kuettner type vertical wind profiles in the atmosphere under conditions of cloud banding suggests that the average

wind in the layer is approximately 0.7 times the maximum wind.

Windspeeds computed following this procedure compare with those computed from ground truth to within a factor of 2. A problem here is that for many Landsat photographs no adequate surface and upper air observations can be found, so that our estimate of the accuracy of cloud band derived average windspeeds is probably rather conservative.

3. DATA USE

Landsat-2 data ordered 18 November 1975 arrived in December. No additional data has been ordered since this last order arrived. Thus, the data usage is as follows.

Value of Data Allowed	Value of Data Ordered (Last Quarter)	Total Value of Data Received
$1600	$392.00	$588.00

4 NEW TECHNOLOGY

No new technology has been developed during this reporting period.

5. PROGRAM FOR THE NEXT REPORTING PERIOD

Analysis of the cumulus banding and wave clouds will be completed, tabulated and compared with ground truth and the suitability of existing theory for wind profile computations from banded cloud patterns over data sparse areas will be evaluated.

Descriptive accounts will be given of cases which do not support the simple models used throughout this project, but which are of scientific or operational interest.

6 CONCLUSIONS

The work performed during this reporting period has separated cases of cumulus banding which contradict existing theories of cloud street formation and represent hybrid cloud condition from those with more organized cloud streets. The latter hold promise for a reasonable quantitative estimate of flow characteristics and airmass properties over data sparse areas.

9. RECOMMENDATIONS

The work performed during the reporting period has not led to any recommendations for changes in the operation or investigative effort.